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ALL-OPTICAL SWITCHING BASED ON INDUCED WAVELENGTH SHIFT IN A CDSSE-DOPED FIBER

University of Connecticut

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ALL-OPTICAL SWITCHING BASED ON INDUCED WAVELENGTH SHIFT IN A CDSSE-DOPED FIBER

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13. ABSTRACT *(Maximum 200 words)*
A non-linear, doped speciality fiber was fabricated consisting of cadmium sulfur selenide (CdSSe). The fiber had a core composed of a Schott Glass material (RG630). The RG630 is a CdSSe/glass composite material in which the semiconductor is in the form of nano-spherical particles with average diameter of 3.7 nm and occupies a volume fraction of 0.32%. Previous theoretical modeling indicated that such a semiconductor doped fiber would have a nonlinear refractive index higher than ordinary silica fiber and yet have losses low enough to be of practical significance. Three major phases of the effort were performed. Phase-I; fabrication of the fiber for single mode operation in the wavelength region of 1300 nm and 1550 nm (communication wavelength regions), Phase-II; characterization of the linear performance of the fiber (ie; transmitivity and absorption coefficient were determined), and Phase-III; characterization of the nonlinear refractive index of the fiber. The response time of nonresonant effects were measured between 1-10 ps. This suggested that such a fiber could be used to design ultrafast optical switches and modulators.

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A. Technical Summary

This report summaries a one year activity the main objective of which was to fabricate a cadmium sulfur selenide (CdSSe-) doped specialty fiber and to characterize both the linear and nonlinear properties of the fiber. The motivation was to produced a highly non-linear fiber which can be used eventually to produce optical components such as all-optical modulators and switches that are compact, robust and require laser diode power levels to actuate them. The fiber we fabricated had a core made of an RG630 Schott Glass material. The RG630 is a CdSSe/glass composite material in which the $CdS_{0.5}Se_{0.5}$ semiconductor is in the form of nano-spherical particles with average diameter of 3.7 nm and occupy a volume fraction of 0.32 percent. We had previously made theoretically modeling to indicate that, such a semiconductor doped fiber can have nonlinear refractive index higher than ordinary silica fiber and yet have losses low enough to be of practical significance.

There are three major phases of the program. Phase I involves the fabrication of the fiber for single mode operation in the wavelength region of 1300 nm and 1550 nm communication wavelength regions. Phase II involves the characterization of the linear performance of the fiber such as its transmitivity and absorption coefficient, and in Phase III we characterize the nonlinear refractive index of the fiber. The nonlinear refractive index was measured at a wavelength of 1312 nm which is in the nonresonant regime of the operation of the fiber. Response time of nonresonant effects are typically between 1-10 ps for CdSSe/glass composite and therefore such a fiber can be used to design ultrafast optical switches and modulators.

B. Fiber Fabrication.

The fiber cladding was fabricated from a B270 glass. A thick cladding wall was formed from two rods of B270 glass. The rods were drilled at the center to form glass tubes of inner and outer diameters of 0.212 inches and 1.35 inches respectively. The inner and outer diameters were polished to ensure a better surface for sealing during the draw process. One tube was drawn to 0.200 - 0.210 inches outer diameter by 0.03 inches inner diameter to fit inside the larger tube to build up the desired cladding wall thickness.

A core bar was produced by grinding and polishing a block of RG630 into a cylinder about 0.25 inches diameter by 6 inches long. It was then drawn to 0.029 inches outer diameter to fit the inner diameter of the inner tube in assembly. The assembly consisted of the three items described above assembled together. The core bar (0.29-inch diameter) was inserted into the smaller tube (0.02-in OD by 0.03-in ID). The smaller tube containing the core was then inserted into the larger tube (1.35-in OD x).212-in ID). The assembly was held together by mechanical means at the top end and attached to the feed mechanism of a draw tower. After the bottom of the assembly was heated and sealed, a vacuum was created inside the tubes allowing air pressure to collapse the tubes around the core, eliminating the air spaces between them during the drawing process.

Table 1 describes the different types of fibers drawn. The refractive index of the core and cladding were measured using ABBE refractometer as 1.53 and 1.522 respectively.

Table 1: Types of CdSSe-Doped Fibers Fabricated.

Sample	Core Material	Cladding Material	Core Diameter µm	Outer Diameter µm
A	RG 630	B 270	4	200
B	RG 630	B 270	5	250
C	RG 630	B270	6	300

C. Linear Characterization Of CdSSe-doped Fiber

The linear properties of the fiber was characterized in terms of its absorption coefficient and transmitivity. The absorption coefficient is a useful parameter in determined the practical usefulness of the fiber in implementing devices. Also by comparing the absorption coefficient of the fiber with that of the bulk material some inferences can be drawn about losses introduced due to the fiber fabrication and pulling process. The transmittivity was needed to determine the range of wavelengths for which the fiber could be operated in the nonresonant regime. The experimental procedure for the absorption coefficient and for the transmittivity were based on the "Cut-back method" and the "White light source technique" respectively, and are described in detail below.

I. Measurement Of The Transmittivity Of The Fiber.

The transmittance of the fiber over a wavelength range between 380 and 1800 nm was measured using a tungsten filament white light source. The white light source was focused onto one end of approximately 16 cm length of the fiber. The output end of the sample fiber was focused onto the input aperture on an ANDO AQ1425 Optical Spectrum Analyzer. The transmission measurement of the Sample is shown in Figure 3. For comparison, the transmission measurement result of a 2.5 cm long rod of the RG630

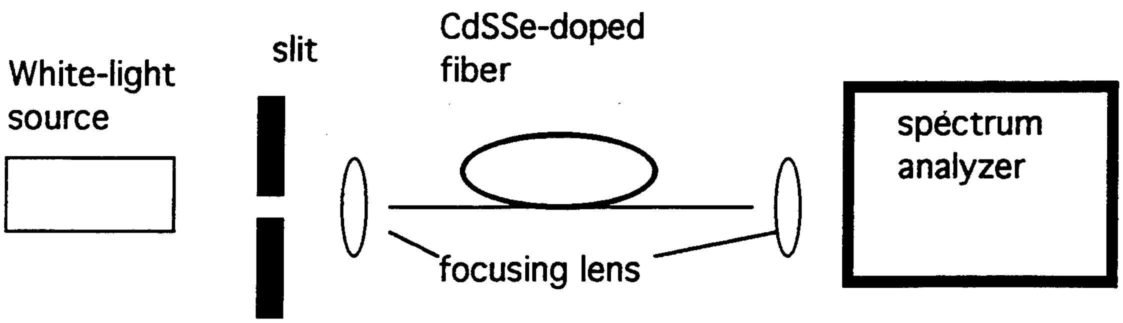


Figure 1. Set-up for measuring the transmittance vrs wavelength fot the CdSSe-doped fiber.

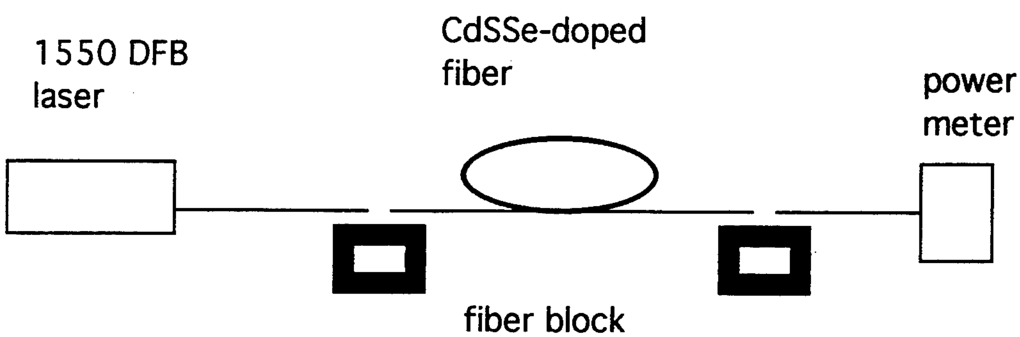


Figure 2. Set-up for measuring the absorption coefficient of the CdSSe-doped fiber. The measurement was made at a wavelength of 1550 nm.

core material is also included. The quantitative levels of the two measurements are greatly different. This difference is due to the diffraction limited focusing of the white light filament reducing the available power that can be launched into the core. qualitatively however, the position of a measured absorption edge is the same for both materials and located near the expected value of 630 nm for this glass type. This results indicates that the CdSSe of the RG630 glass material has survived the fiber fabrication process and should result in similar properties as that found in the bulk material.

II. Measurement Of The Absorption Coefficient Of Fiber.

A cut-back method was used to measure the linear absorption coefficient of the fiber. The set-up for this experiment is as shown Figure 2. The source is a 1532 nm DFB pig-tailed semiconductor laser diode. The test fiber was mounted on two flexure stages. The pig-tailed laser was butt-coupled to one end of the fiber. An optical imaging system, located at the opposite end of the test fiber and comprised of an IR photocathode camera and a monitor, was used to observe and ensure that the source signal was well coupled into the core of the fiber before performing the cut-back measurement. Imaging results indicated that a large amount of scattering occurs in the sample fibers and is probably the largest contribution to the measured absorption coefficients. A standard single-mode fiber SMF-28 was used to collect the light from the sample fiber and deliver the power propagating in the core of the fiber to a photodiode detector. A Newport 835 power meter with an 818-IR detector was used to measure the output power.

An initial length (about 50 cm) of the test fiber was used. The output power was measured for different input power levels to ensure linear absorption. A known length of fiber was then cut-off from the detector end of the test fiber, and the output power again measured for the same set of input power levels. This procedure was repeated for additional cut-backs and an average of the results was made after calculating the absorption coefficient according to,

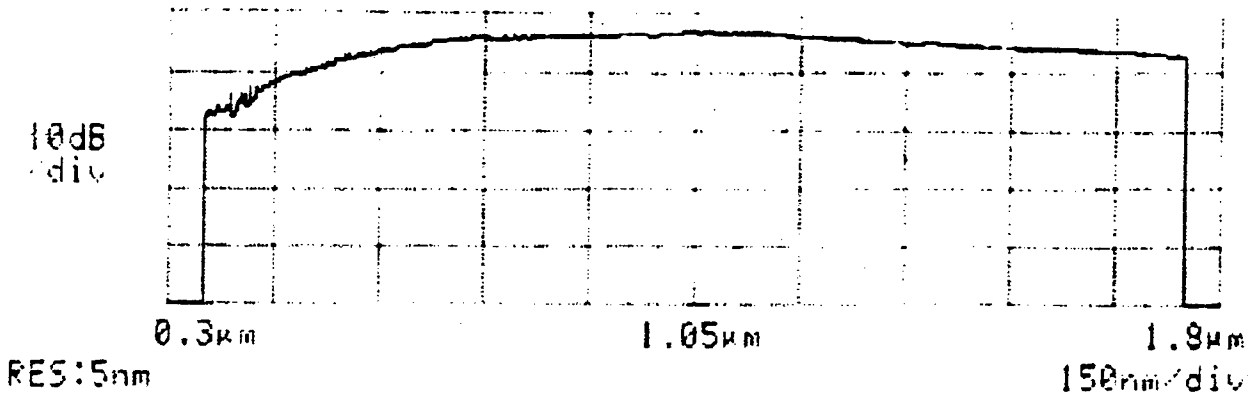


Figure 3a: Transmittivity vrs wavelength for the CdSSe-doped Fiber. The wavelength was from 300 nm to 1800 nm. The fiber shows a fairly constant transmittance for wavelength from 700 nm and above.

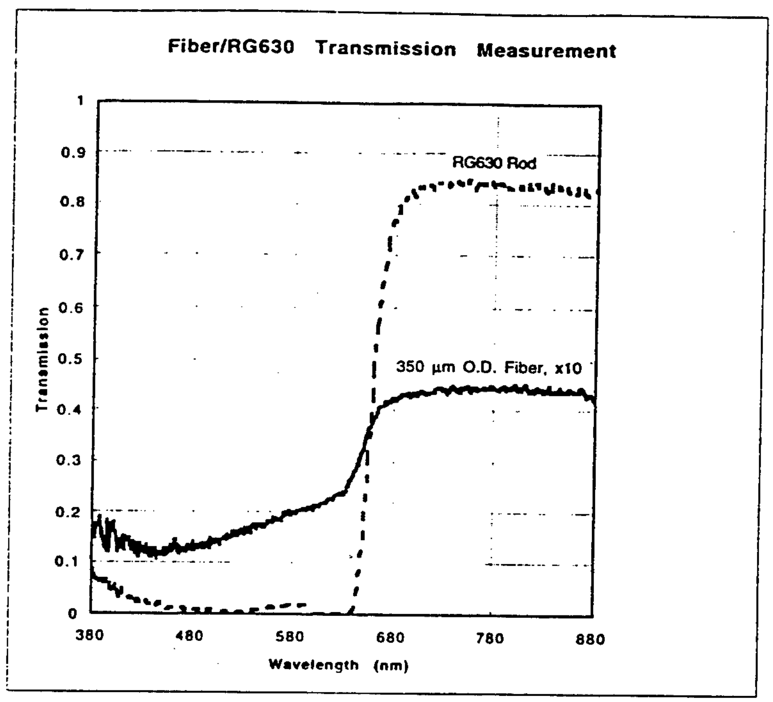


Figure 3b. Transmittivity vrs wavelength from 380 nm to 880 nm for the fiber and for the core material. The two plots show identical absorption edge.

$$\alpha(dB/cm) = \frac{1}{L(cm)} 10 \log \frac{P_{out1}}{P_{out2}} \qquad (1)$$

where P_{out1} is the measured output power prior to cutting and P_{out2} is the measured output power after cut-back. The absorption coefficient was measured to be 0.14 dB/cm. Excess losses due to butt-coupling totaled -5.4 dB. Assuming -0.6 dB for Fresnel losses at the glass/air interfaces, excess losses are -4.8 dB.

D. Measurement Of The Nonlinear Refractive Index

Two separate measurement were made in order to calculate the nonlinear refractive index of the CdSSe-doped fiber. One of these experiments was the determination of the beam waist of the laser beam at the focal plane of the lens. The second experiment called "Z-SCAN" was a measurement of the transmittance of the sample as it scanned through and beyond the Raleigh range of the lens. The characteristics Kerr effect of the CdSSe-doped glass causes it to act as a lens. This implies that the sample acts as a second lens in series with the focusing lens. The transmittance measures the combined action of the series, and by applying the appropriate theory the nonlinear refractive index of the CdSSe/glass material is determined.

I. Measurement of Laser Beam Waist at the focal Plane.

The set-up is as shown in figure 3. The laser is a 1313 nm Quantronics ND:YLF pulsed laser, with a pulse repetition rate of 100 MHz and a pulse width of 70 pS. The maximum average power of the laser is 1.2 W. The laser beam was directed unto a plano-convex mirror. A 100 mm aperture was attached to an integrating sphere, placed at about the focal plane of the lens. The sphere was mounted on an XYZ-stage. The axes of the stage were adjusted till maximum power was measured by a detector also attached to the

sphere. The aperture was replaced with 50 μm, 25 μm,, 10 μm, and the experiment was repeated. The power at the focal plane was also measured with no aperture.

Here r_o is the radius of the laser beam measured to be 3 mm. P_a is the power measured through an aperture, and P_o is the power measured with no aperture. The beam waist was found to be 20μm.

II. Z-SCAN Measurement For The RG630 Core Material

The experimental procedure follows the Z-Scan technique. A set-up is for the experiment is shown in figure 5. The laser is a 1313 nm Quantronics ND:YLF pulsed laser, with a pulse repetition rate of 100 MHz and a pulse width of 70 pS. The maximum average power of the laser is 1.4 W. The power was controlled with the variable attenuator. A microscope slide was used to split of a fraction of the laser beam, the beam was detected and served as the reference signal for the Z-SCAN measurements. The remaining portion of the laser was directed through a series arrangement of an isolator, mirror and a plano-convex mirror unto an RG630 sample. The sample was mounted on a translation stage. A detector, with a 100 μm aperture attached to it, was place 20 cm from the focal plane of the lens. The sample was scanned through the focal plane of the lens at intervals of 1 mm. The power of the two detectors were recorded at each new sample position, z. Normalized transmittance measured at power levels of 1.1 W, 1.2 W and 1.4 W are shown in figure 6a-cc respectively. The transmittance was normalized to the transmittance at distances far away from the focal plane. From these measurements the nonlinear refractive index n_2 was determined using the equation.

$$n_2(esu) = \frac{\Delta T_{p-v}}{I_o(t)}\left[\frac{1}{0.046(1-S)^{0.25}}\right]\frac{2\pi}{\lambda}\frac{\alpha}{1-e^{-\alpha L}}\frac{2n_o}{40\pi} \qquad (2)$$

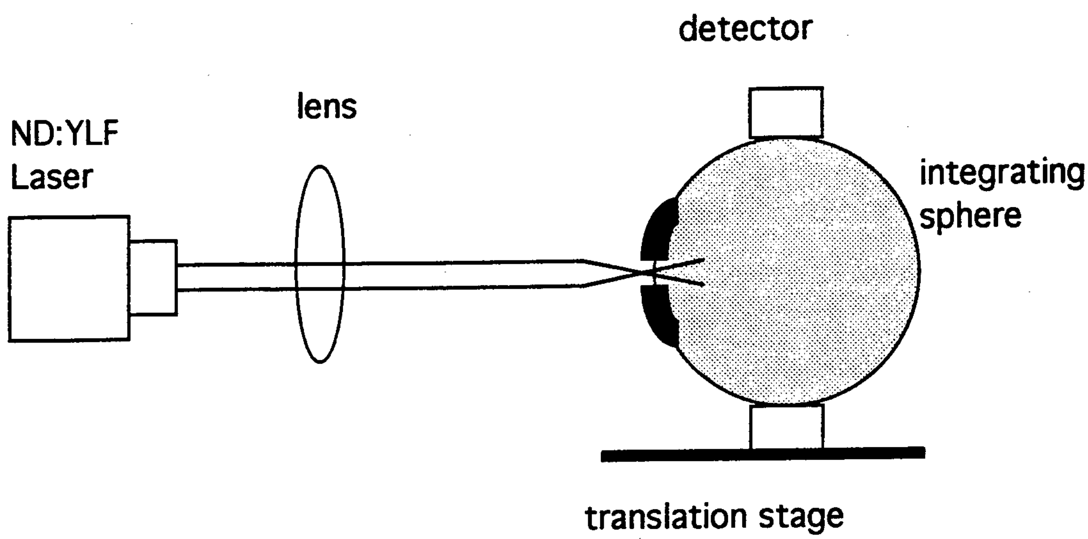


Figure 4. Measurement of laser beam waist

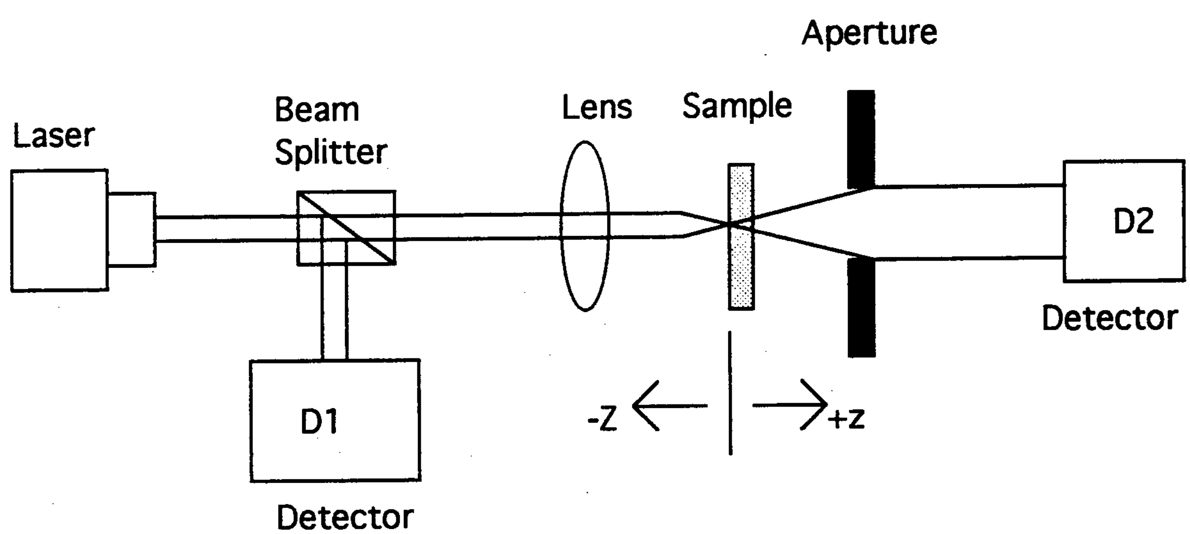


Figure 5: Z-Scan set-up for measuring n2

Figure 6a: Normalized transmittance vrs position. The peak power 1.2 watt

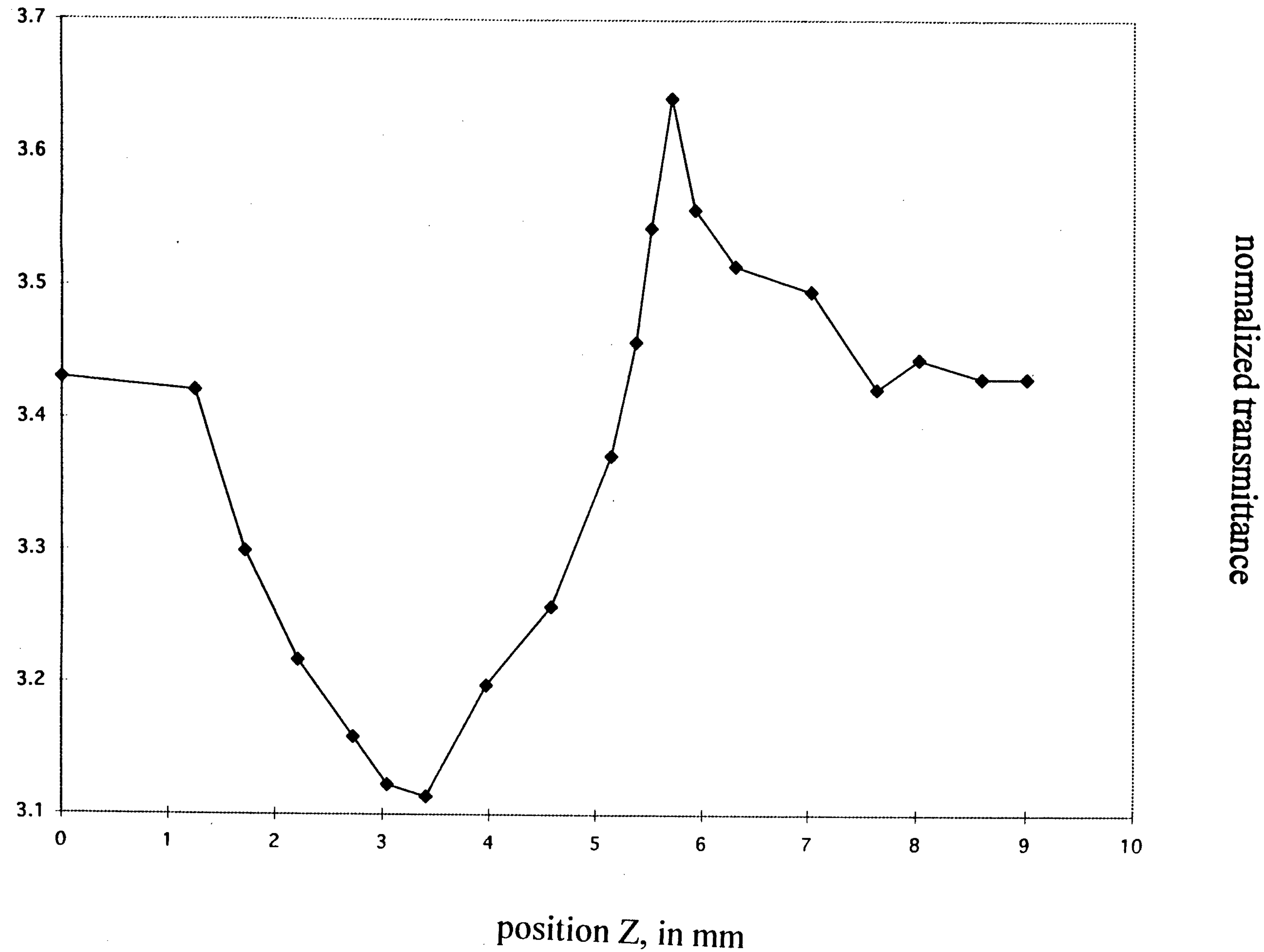


Figure 6b: Normalized transmittance vrs position. The peak power 1.1 watt

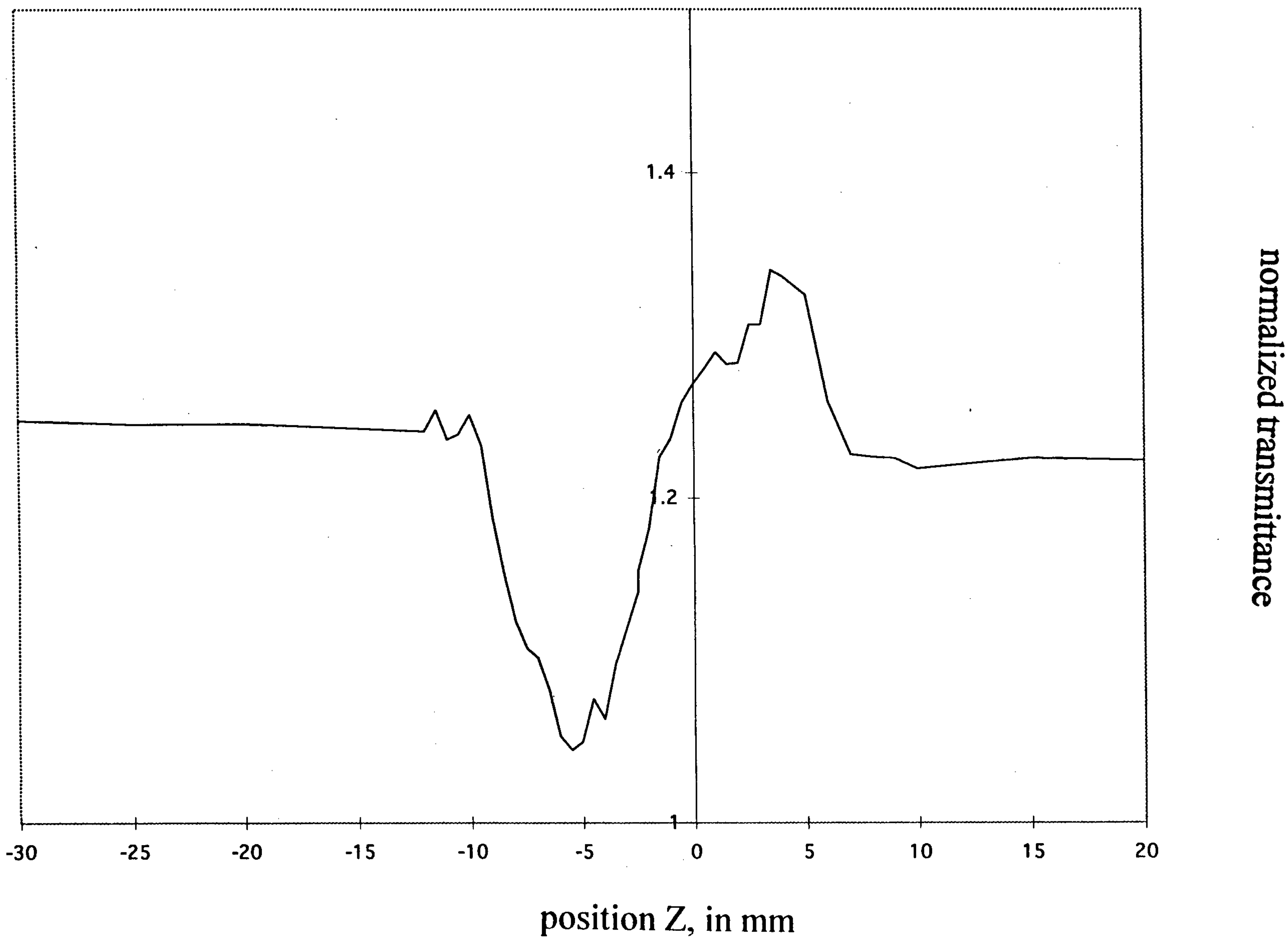
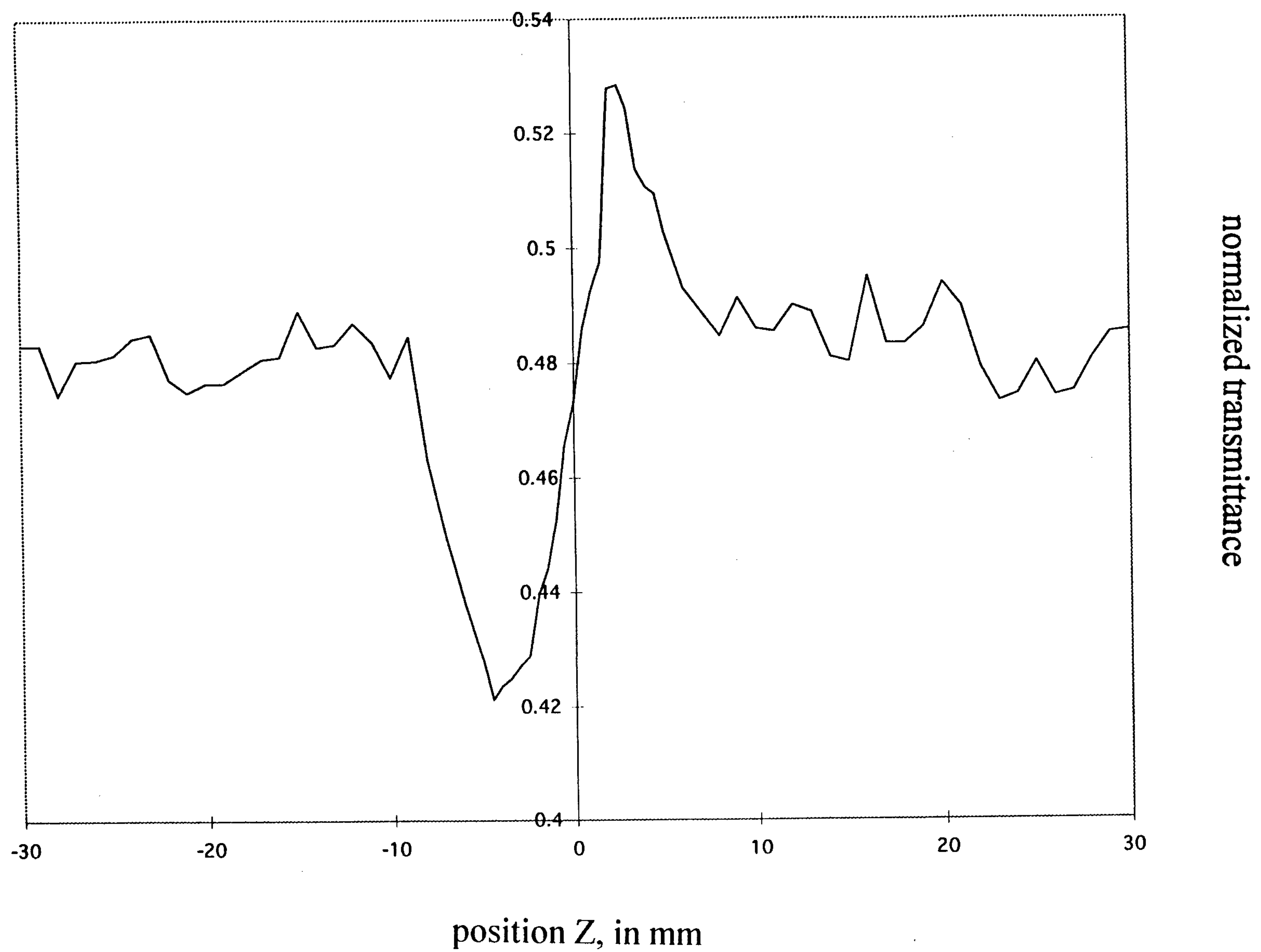


Figure 6c: Normalized transmittance vrs position. The peak power 1.0 watt



Here:

ΔT_{p-v} ≡ Peak-to-valley change in transmittance.

$I_O(t)$ - is the peak intensity of the laser source signal

S - is the aperture linear transmittance

L - Sample thickness

n_O - linear refractive index of fiber.

The nonlinear refractive index was calculated for the three power levels of 1.0W, 1.1 W, and 1.2W and an average for the nonlinear refractive index was found to be measured $n_2 = 1.8 \times 10^{-17}$ m^2/W at 1313 nm.

Discussion/Conclusion.

We have successfully fabricated a CdSSe-doped fiber. Both its linear and nonlinear characteristics have been characterized. The transmittance of the fiber is constant for the wavelength range from 800 nm to 1800 nm. The Absorption coefficient was measured to be .14 dB/cm. This is about 10 times the theoretical limit for such semiconductor/glass composite. We believe that most of the loss occur at the core/cladding interface as we observed high scattering of the laser beam using a CCD camera. The nonlinear refractive index was measured to be $n_2 = 1.8 \times 10^{-17}$ m^2/W at 1313 nm. This value is 400 times higher than ordinary silica fiber. Therefore even with the relatively high loss, this fiber has the potential for implementing compact optical devices that can be actuated at laser diode power levels.

The original "Statement Of Work" included a prototype all-optical switch using the CdSSe-doped fiber as a Kerr medium. However, this could not be achieved due to technical difficulties. The switching mechanism which is based on wavelength shift of a probe signal copropagating with a pump signal in the Kerr medium, required very short 1-10 pS, very stable pulses. Unfortunately the ND:YLF laser could not produce such stable pulses.

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